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# Applicability of Public Domain AG100: ASTER Global Emissivity Dataset 100m V003 for Geothermal Area Prospect Selection at early stage of exploration

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## ABSTRACT

Geothermal area is often characterized by elevated ground temperature observed from satellite remote sensing. Nowadays, such data is freely available from public domain and can be used directly for various studies including geothermal exploration. In this paper we present lessons learned from using ASTER Global Emissivity Dataset (ASTER GED) for geothermal prospect area selection in the early stage of exploration. Two geothermal areas, Patuha and Arjuno, were investigated for their temperature anomaly characteristics in ASTER GED images. The results reveal of prospect areas that are in agreement with elevated temperature in the images. Field checking confirmed the occurrences of geothermal manifestation such as hot springs, fumaroles or even subtle evidences such as warm ground at several centimeters depth in those areas. Some anomaly areas are subjected for further studies or site visits. We conclude that ASTER GED can be used as one of potentially powerful exploration data in early stage of geothermal exploration.

## 1. INTRODUCTION

The surface of a geothermal area often characterized by some anomaly such as elevated ground temperature, vegetation stress due to low pH soil containing acid steam heated fluid, rock alteration, active manifestation such as hot springs, fumaroles, steaming ground and many others. This is commonly due to hot fluid raising from the depth to the surface. The anomaly, if it is distributed in relatively large area, can be detected with satellite image. Identification of geothermal anomaly area from satellite imagery is very useful for geothermal exploration, in particular at the early stage of the exploration.

In this paper we present lessons learned from using ASTER Global Emissivity Dataset (ASTER GED) for geothermal prospect area selection in the early stage of exploration. The method is intended to identify average ground temperature from several years. It is assumed that prospective area will show higher ambient temperature because it consistently emit heat from geothermal activity. Obviously, for a long periods of time there must be fluctuation due to several factors such as human activities, rainy and dry season and many more. This fluctuation or changes are observed as standard deviation of average temperature value. The more changes occur in an area, the higher the fluctuations and so does the standard deviation. In the geothermal anomaly area, it is expected that the standard deviation of the average anomalous temperature will be low, because the amount of heat emitted from the ground is too high to be disturbed by the activity. The higher than normal average temperature in geothermal anomaly area can be accompanied by unhealthy vegetation or also called 'vegetation stress'. Although the ground temperature anomaly is subtle, but the effect to vegetation health might be significant. The level of vegetation health can be identified by satellite imagery using a method Normalized Diverent Vegetaion Index or NDVI method. Thus, by combining the average temperature for a long period, its standard deviation and NDVI value in a suspected geothermal anomaly area, we can delineate the most prospective area for further detail exploration program.

Suryantini et al. (2013) has proposed NDVI application for geothermal exploration by analyzing the probable cause of NDVI in geothermal fields. In geothermal area, the occurrence of thermal manifestation often caused vegetation stress due to acid fluid or high temperature. By mapping the area with low NDVI value that might indicate vegetation stress, the potential area of manifestation, even for concealed features, may be delineated.

## 2. DATA AND METHOD

The science data products in the ASTER GED v3.0 was acquired by processing millions of cloud free ASTER scenes over a 9 year period from 2000 to 2008, at 100 meter spatial resolution (nominal) by USGS NASA (Hulley et al., 2012; Hulley et al., 2015). It includes the mean and standard deviation of surface temperature and normalized difference vegetation index (NDVI) used in this research. Thus, for every pixel, there are values of calculated average (mean) and standard deviation of temperature or NDVI, from 9 year of measurements. In practice, there are less in number of observations (from 0 to 30 observations) for every pixel, probably due to processing algorithm applied in order to obtain the best quality data.

ASTER GED v3.0 data are already available in a ready-to-be-used format for research purposes without further processing. It can be downloaded from USGS EarthExplorer website, under ASTER Global Emissivity Datasets: ASTER GED AG100. The data is given in HDF5 Scientific Data Set (SDS) format file which can be read and viewed by a number of tools, such as HDFView, MATLAB, and Python (See ASTERGED Documentation and User Guide at its website).

## 3. METHODOLOGY

The methodology used in this paper is to utilize temperature and NDVI data (in the form of mean and standard deviation) for an early reconaissance geothermal exploration data. Inferences to possible geological process that may cause temperature and NDVI anomaly were made with the assumptions that spatial and temporal variation might be related to subsurface geological process. In this method, it is the variations that are important, more than the absolute values themselves, mainly due to uncertainty factors influencing the data. Furthermore, it is assumed that temporal variation is normally distributed (follows Gaussian normal distribution). Those assumptions may not be fulfilled, but nevertheless the physical variations may still be used for exploration purposes. The data may serve as useful early regional data and first aerial mapping of physically inferred (i.e. temperature and vegetation stress) shallow subsurface condition for geothermal exploration.

Interpretation of temperature mean and NDVI mean maps are relatively straightforward. It is used as a direct qualitative indicator of possible anomaly in the subsurface related to thermal activity of the target area. Thus, clusters of high temperature area may indicate the proximity to main thermal source, while clusters of very low NDVI may indicate highly altered area caused by thermal activities.

On the other hand, standard deviation of temperature is variation of temperature in a specific location. A cluster area of high standard deviation temperature in the map means the area is experiencing higher fluctuative temperature than its surrounding, and vice versa. There are several factors that may contribute to this temperature fluctuation, for example, differences in rock thermal conductivity, water content or groundwater table fluctuation, and may also simply due to seasonal variation. In the case of NDVI standard deviation map, it has been demonstrated by Seeyan et al. (2014) that temporal variation in NDVI map is related to groundwater table depth variation.

It is the combined interpretation of both map (mean and standard deviation) that may give further insight to the subsurface conditions and/or characteristics which might relate to geothermal exploration. For example, areas that are characterized by high temperature mean and low standard deviation could represent areas that are constantly hot and do not vary significantly throughout whole year regardless of the season. Areas with such characteristics could be potentially very near main thermal anomaly area (possibly upflow). On the other hand, areas that are characterized by relatively moderate to high temperature mean and high standard deviation could potentially be areas that are permeable (possibly outflow) and their temperature vary seasonally. In the case of NDVI, high standard deviation areas could represent areas of permeable zones that may be associated to lithology, lithology boundaries, faults, and/or discharge/recharge area (regardless of high or low NDVI mean).

To be able to interpret and delineate anomaly areas that are associated with geothermal energy potential, at least 7 image images must be compared with each other. These images are:

(1) True Color Composite (TCC) to see land cover conditions which will then be useful for separating anomaly which may be caused by geothermal or other activities such as human activities, such as cities, gardens etc. In this research, Google Earth is used.

(2) Digital Elevation Model (DEM) to identify the topography of an area which may relate to the estimated temperature of the area. For example in elevation areas > 2000 m, generally the average temperature is <20 ° C

(3) Geological map and location of manifestations, which will be useful for validating the presence of geothermal anomalies or not

(4) Image of temperature average (Temp. mean) that will be used as an initial indication of occurrence of thermal anomaly. Usually if the temperature image has a higher average value than the surroundings, it will be an initial indication of thermal anomaly in the area.

(5) Image of Temperature Standard Deviation, which is useful to see the fluctuations of temperature data values. If the value of the standard deviation is high, then there are minimum and maximum values which have a considerable difference from mean values. This can be interpreted as the presence of geological conditions or non-geological conditions that control this deviation. For example, a large standard deviation means that it may be caused by porous and permeable rocks so that the soil temperature in this area is strongly influenced by rainfall that changes throughout the year, compared to its surrounding area. When the rainfall is high, the soil will show a relatively low average temperature while in the dry season it will show a relatively high temperature.

(6) Normalized Different Vegetation Index (NDVI) mean (average) imagery, it will be useful to look for thermal anomaly regions that are associated with vegetation stress or bare ground.

(7) NDVI Standard Deviation Image, will be used to associate the vegetation stress anomaly with ground water conditions which are controlled by rock type and permeability. In NDVI anomalies with a large standard deviation, it can be expected that there are rocks with large permeability that may contain thermal water. Fluctuations that occured are generally caused by external factors such as rain or other. Nevertheless, it is possible that fluid in permable rocks is not related to thermal fluid but other and can cause stress vegetation.

The purpose of interpreting the above images is to find as many anomalies as possible in each image which will most likely be related to geothermal activities such as concealed outflows, surface manifestations, and so on.

The sequential flow of interpretation is as follows:

1. *Interpretation of NDVI Anomaly*. Determine areas with low NDVI anomalies (or sometimes moderate). Compare this data with True Color Composite (TCC) whether it's in a man made location like a city or other. If so, this anomaly may not be related to thermal activity, it can be ignored. If it is not in a manmade location, it can be considered to be caused by thermal activity. NDVI anomaly locations can be validated by the presence of surface manifestation maps, such as the location of low NDVI anomalies located in craters and usually adjacent to solfatara or fumaroles usually can be ascertained related to thermal anomalies. Therefore it is very important to understand the location of this low NDVI anomaly by comparing with the DEM image. Next, the standard deviation values will be examined in this area. If the standard deviation value is small then the low NDVI anomaly is assumed to be consistent throughout the year, so that it is not affected by fluctuations in shallow groundwater that may be related to geothermal fluids. If the standard deviation is large, then it can be suspected as a low NDVI anomaly that is affected by fluctuations in shallow groundwater and may contain hydrothermal fluid. Crosscheck with a geological map to add confidence, although sometimes it is not too relevant because the geological map is not too detailed. Areas that are not vegetated or bare ground will show the same thing. Furthermore, delineation of NDVI anomaly area to be integrated with average temperature data and standard deviation.

2. *Interpretation of Temperature Anomaly*. The same process is also done for the temperature mean map and standard deviation. First, identify the area that has a higher than normal temperature. In this research, the normal temperature is assumed to be <24 °C, which is air temperature in general. This value will be considered an anomaly value threshold. In this case the anomaly value of each pixel is not calculated but more qualitatively delineates the area that has a value above normal. On maps Average temperature, map coloring is scaled every 2 ° C range, this makes it easier to see anomaly continuity patterns that might be related to certain geological information. After the zone of mean temperature anomaly has been identified, the next is to validate whether the area is related to human activity or natural, which is expected to be the activity of geothermal fluid. This validation can be done by comparing the initial zone with the TCC image. The area of temperature anomaly that is related to human activity will not be further analyzed, while anomalies because natural processes will be integrated with other data such as geological maps to delineate and interpret geothermal systems. After obtaining an area with a higher temperature than normal, then the interpretation of the cause of anomaly will be carried out, which can be estimated from the standard deviation value. If the anomaly value of temperature is so high (> 10 ° C from normal temperature), it can be assumed that this anomaly is related to geothermal activity. This can be cross checked with the geological map and location of existing manifestations.

3. *Interpretation of Average Temperature Deviation Data*. The spread of high temperature anomalies can be combined with the standard deviation anomaly pattern. Anomaly high in average temperature images may only cover a narrow and limited area, but in reality it can be related to wider hidden or concealed anomalies. This can be seen from the pattern of anomaly standard deviation from temperature images. Not infrequently in the average temperature anomaly image only subtle anomaly value is seen, ± 2-4 ° C above normal, or even equal to the average normal temperature, but on a standard deviation map has a high value, this can also be interpreted as the presence of thermal anomalies (after anomalies related to man made ignored) which may be related to ground water fluctuations that are thought to contain thermal fluid in this area. Furthermore, integration with geological maps and manifestations will answer the cause of the anomaly.

4. After obtaining evidence of thermal anomalies throughout the data, it can be concluded that the area is probably an anomaly area associated with geothermal anomalies. This area will then be recommended for further exploration programs, such as geological mapping or geochemical surveys.

The following are two case studies of the application of the above methods, namely in Patuha and Arjuno-Welirang Geothermal Field.

## 4. CASE STUDIES

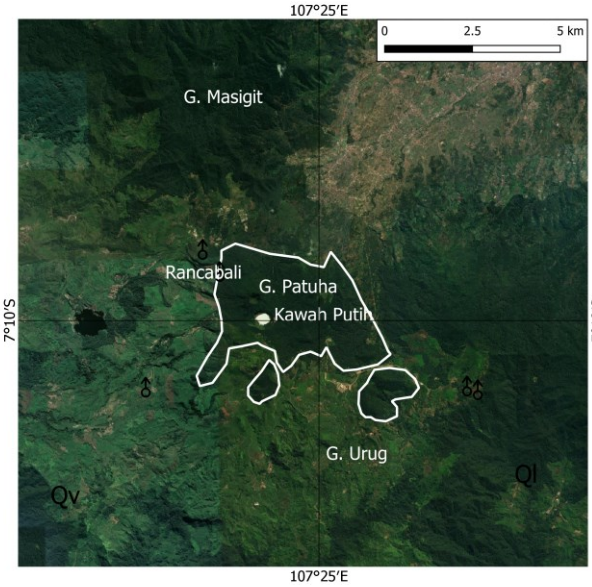
### 4.1. Patuha Case Study

The images of the Patuha Geothermal Field are shown in figure 1a-g. In the TCC image of the Google map (Figure 1a), it can be seen that the area outside the human activities zone is dark green, where the area of interest for geothermal is around Pucak Patuha and Kawah Putih which are limited by circular features, including circular features in the south. In addition the area in G.Urug also has a circular morphological form. The location of other manifestations is very close to the zone of human activities so feared will result in misinterpretation. This area of interest is generally at high peaks as seen in the DEM image (Figure 1b). This high area is usually a conservation area so that human activities can be very limited and hopefully the interpretations are not much wrong. Geologically this area is covered by quarter volcanic products that are very commonly associated with geothermal systems in Indonesia (Figure 1c)

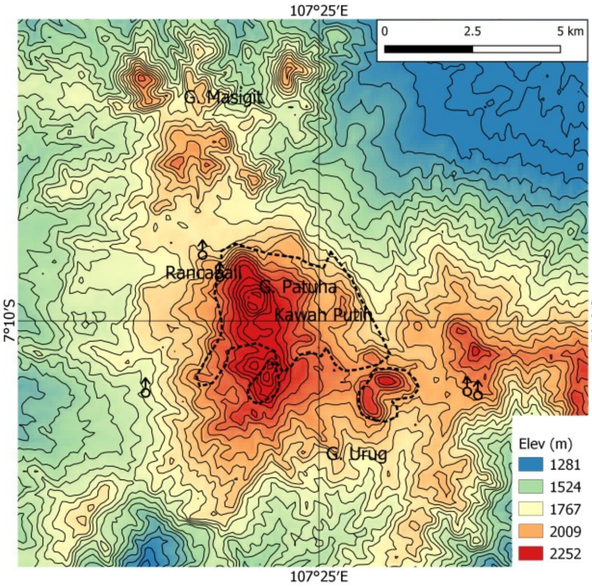
The NDVI image is shown in Figure 1d. It can be seen in the figure that some interest areas correlate with moderate (yellow) vegetation anomalies. This anomaly will be investigated further whether it is related to geothermal activity or not. The standard deviation NDVI image (Figure 1e) shows that the NDVI anomaly correlates with a broader pattern of standard deviation. This raises the suspicion that the possibility of the deployment of vegetation stress anomalies is much greater than that indicated in the NDVI image in Figure 1e. The existence of a moderate-high standard deviation is interpreted as a fluctuation in the NDVI value related to changes in groundwater below it, both chemical changes, temperature and depth. If correlated between NDVI images and standard deviations with geological maps and manifestations and TCC imagery, this anomaly area is closely related to various geological features that have the potential to control the existence of geothermal systems, for example around circular features of a composite volcano that may associate with upflow, around manifestations, or on the slopes of a volcano that may have concealed outflows.

Images of mean temperature and standard deviation are shown in figure 1f and 1g respectively. In the average temperature image, the anomaly area around Patuha and Kawah Putih generally has a mean temperature below normal. This is possible because the location of the anomaly is in a high elevation (> 2000m) so the mean annual temperature is true <24 ° C or even <18 ° C. In some locations, the temperature values in the interest area show values that are rather high than normal, such as in the Kawah Putih area, the SW circular feature, the circular feature in the south of Patuha and in G. Urug. These areas correlate with the standard deviation value that is moderate to high in Figure 1g, so it is assumed that the temperature in the area fluctuates and may be related to the shallow groundwater temperature expected to be associated with thermal fluid.

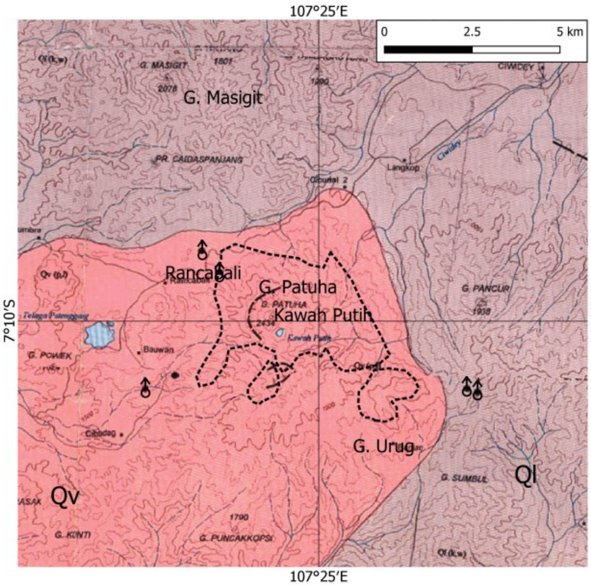
Integration of NDVI anomaly results and standard deviations, mean temperature and standard deviations with the current location of production manifestations and zones which are around G.Urug (not shown in the figure) show that these anomalies from remote sensing are quite relevant in determining the prospects for further exploration. Areas outside the delineated area may have good potential, except that in this method the interpretation is still quite difficult because the location of the anomaly NDVI and the temperature mean are slightly affected by human activity.



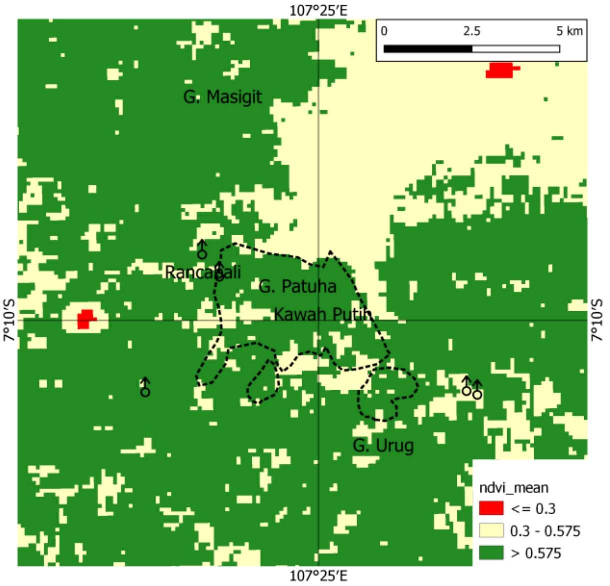

a. Google Earth



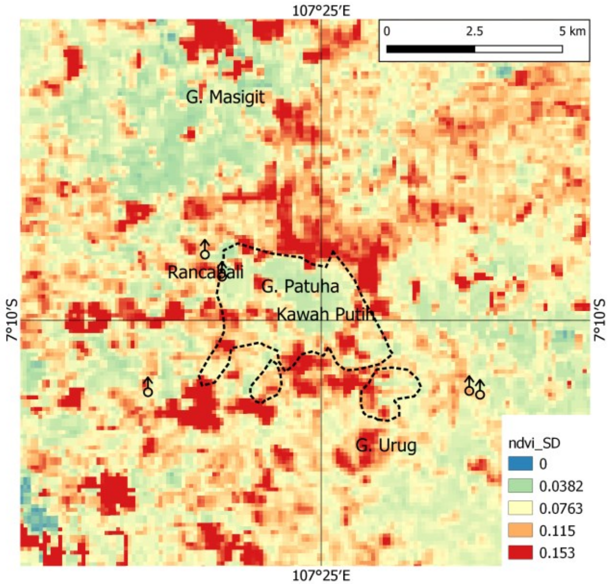

b. DEM



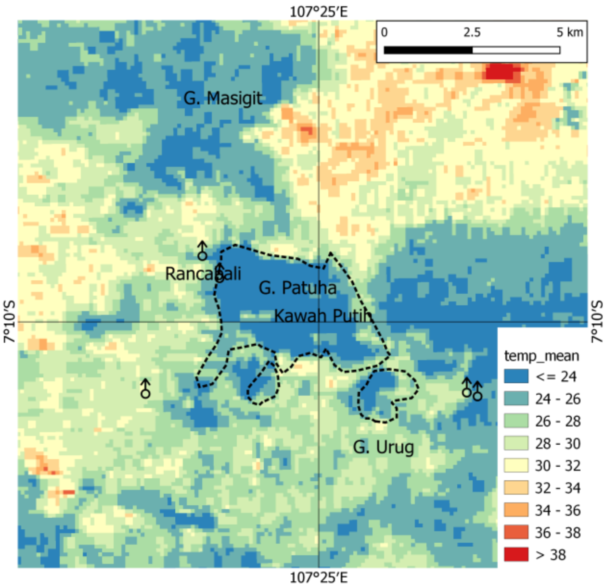

c. Geology



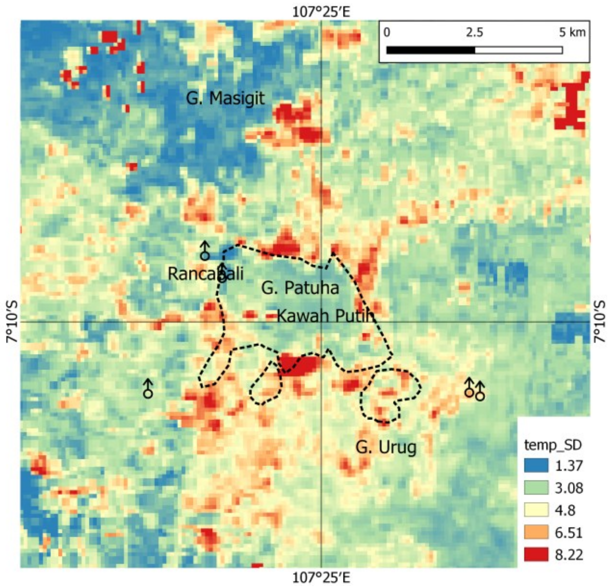

d. NDVI mean




e. NDVI SD




f. Temp. mean




g. Temp SD

**Figure 1: Patuha Geothermal System**

### 4.2. Arjuno-Welirang Case Study

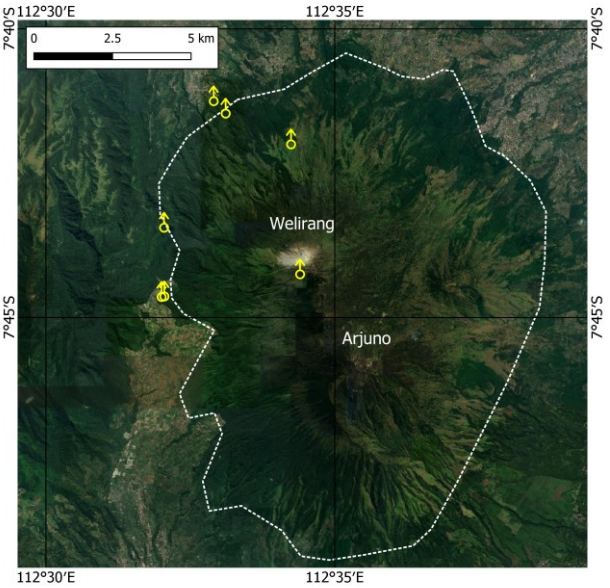
Images of Arjuno Welirang's Geothermal Field are shown in figure 2a-g. This field is a field that is still in the stage of further exploration. Geological, Geochemical and geophysical surveys have been completed in this field. In the TCC image from Google map (Figure 2a), it can be seen that this field is generally associated with a composite volcanoe, where the eruption center is younger towards the north. From old to young, from south to north the eruption centers are Arjuno which is a very large crater opening to the southeast, Bakal, Kembar-2, Kembar-1 and Welirang (Figure 2c). At present Welirang is the most active crater, which emits sulfur until it can be mined. In the TCC image, Welirang is seen as an area that has no vegetation and is white due to the surrounding vapors and gases. On the west there is Batu City while in the north there is Pringen City. The area of interest that might not be disturbed by human activity is described as the white line in Figure 2a or blue at 2b. This area covers a large area and in the TCC image is not too green which is suspected that vegetation in this area is not too thick.

In NDVI imagery (Figure 2d) it can be seen that low NDVI anomalies cover areas on mountain peaks ranging from Welirang, Kembar-1, Kembar-2 and Bakal, and a little in the northern part of Arjuno. This area is prioritized for field geological surveys and anomaly checks. Around this low NDVI anomaly there is moderate anomaly. This area may be important for surveying, but it falls into a lower priority. Outside the moderate anomaly area there are areas with healthy vegetation.

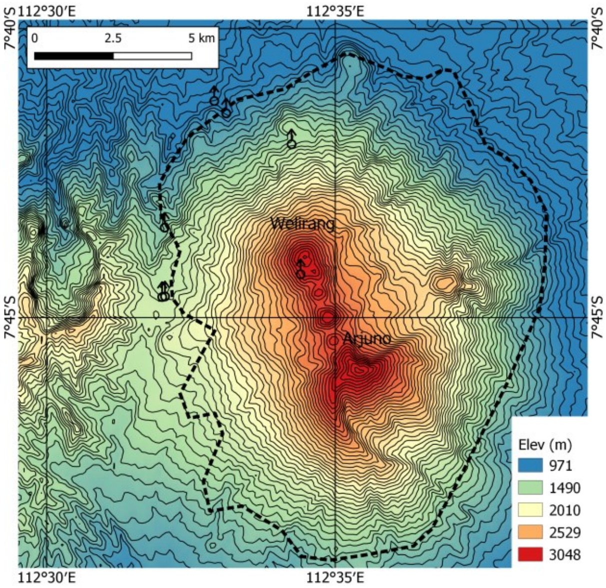
In the low anomaly area on the mountaintops, the standard deviation value varies from moderate to high which indicates a fluctuation in shallow ground water although not significant, except in the Welirang crater with a very high standard deviation (red). In areas with moderate anomaly, to the west, the standard deviation value is generally high, indicating significant groundwater fluctuations. Likewise in areas that have high NdVI values or areas with healthy vegetation, namely in NE and E from twin mountain peaks, these areas have high NDVI standard deviation values, so it is assumed that there is a concealed outflow. This is quite evident for the NE region because at this location a warm water manifestation appears.

The standard deviation image of the mean temperature (figure 2g) shows that in the peak area to the west and east slopes, the standard deviation value varies greatly from moderate to very high even though the mean temperature shows relatively low and uniform. This is presumably a shallow ground water fluctuation. This groundwater is expected to carry thermal fluid.

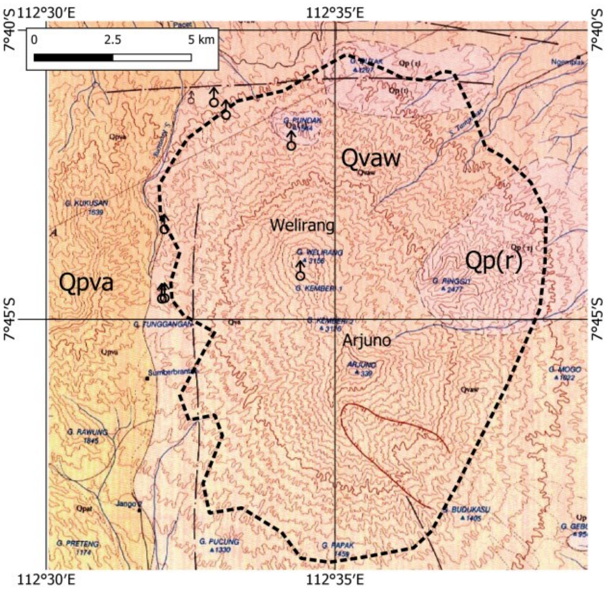
Based on NDVI anomalies and standard deviations and temperature mean anomalies with standard deviations, the most dominant interpretation of the anomaly region was made (dark circles in Figure 2g). Seeing its location not far from the center of the eruption, it can be expected that this area is related to the reservoir inside. This needs to be further proven. Based on the results of the last survey, the area (black circle) is the reservoir area, especially the area to the west.



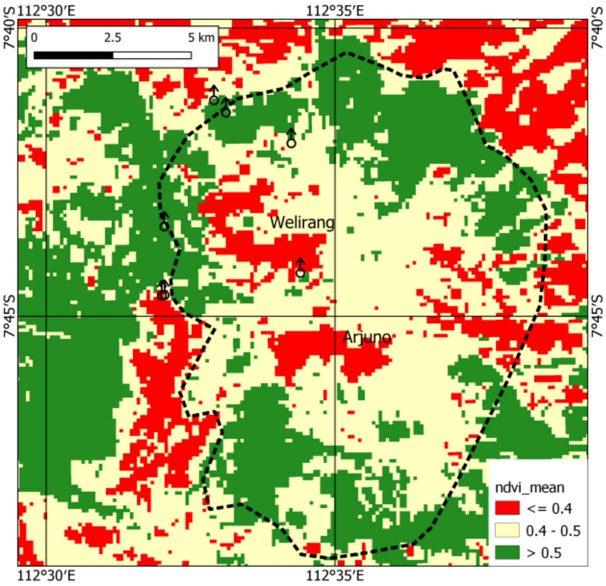

a. Google Earth



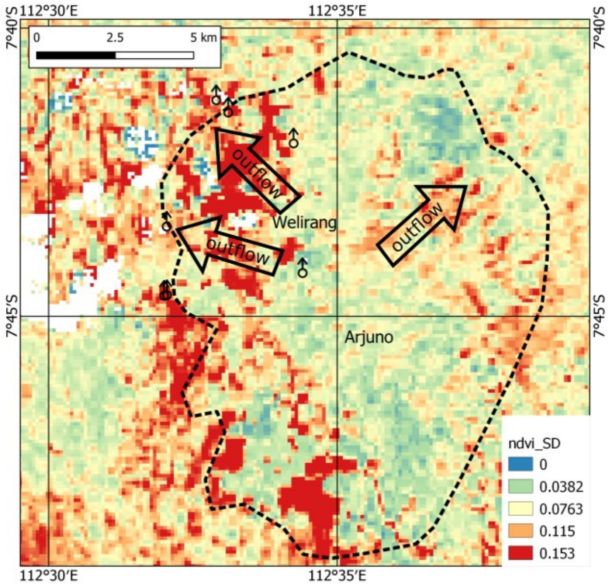

b. DEM



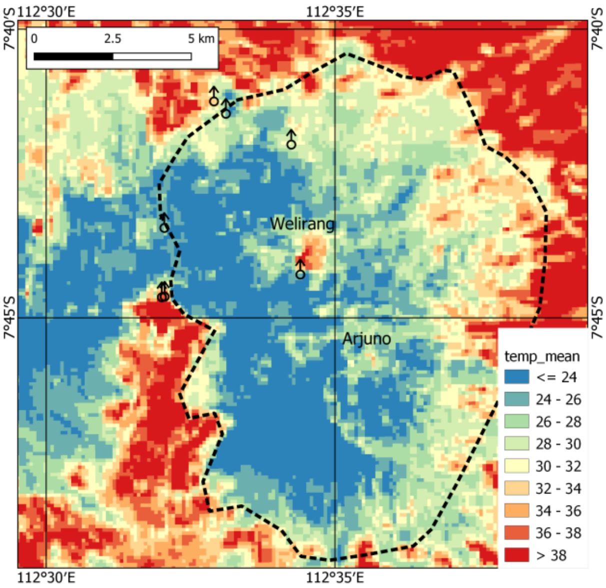

c. Geology



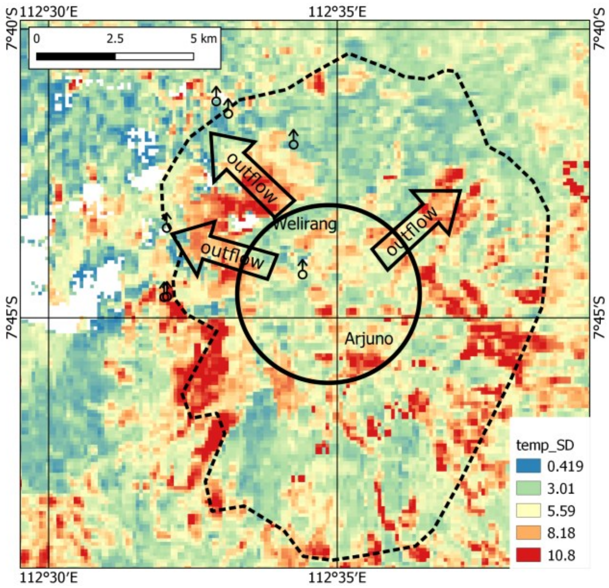

d. ASTER GED NDVI




e. ASTER GED NDVI. SD




f. ASTER GED temp mean




g. ASTER GED Temp SD

**Figure 2 : Arjuno-Welirang Geothermal System**

## 5. CONCLUSIONS

Mean and standard deviation of temperature and NDVI may correlate to hydrological condition in the area which can be used to map potentially permeable area (infered from higher standard deviation values) associated with geothermal activities. Nevertheless NDVI classification need to be checked with ground features in TCC image to eliminate possible phenomena not related to geothermal activities.

ASTER GED may provide additional tool that can be used for early geothermal exploration. It is free and contains spatial and temporal information that can be used to investigate surface phenomena over an area that may relate to subsurface condition in a potential geothermal prospect.

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